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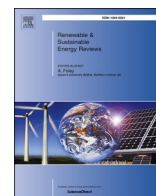
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Rambling facets of manure-based biogas production in Europe: A briefing

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ABSTRACT

The use of biogas has been considered a strategically distinctive option for the entire transition to renewable fuels. The wide gap between the use of fossil- and biomass-based fuels calls into question how the business of gas-based energy must be changed to alter the inequalities between biogas and natural gas. The deployment of biogas-derived methane is delayed in contrast to the syngas-derived methane. Subtle issues are spotted and highlighted amid the application of anaerobic digestion to detect fundamental changes in the bioenergy landscape and underpin the drive for global sustainability; lastly, an outlook is suggested for how the field may progress in the future.

1. Introduction

Due to the wobbling prices of the natural gas and the global concerns about climate change, biogas has been proposed as an alternative bio-energy source [1,2]. The challenges in anaerobic digestion (AD) adoption as a paradigm shift rely on new technological findings, a better biological understanding to increase yield and production rate and to remove hurdles in reforming the legal regime [3,4]. The application of emerging advanced technologies is indispensable to boost the biogas industry and tackle environment-associated problems [5–10]. Understanding the interplay of critical factors affecting the biogas industry may establish a more significant share of the biogas in the European economy [11].

Industrial biogas plants mainly consist of several process units (Fig. 1) starting with a storage tank where manure is homogenised, the digester where the anaerobic digestion takes place, an effluent tank, and a gas-upgrading facility [12]. The complex composition of (in)soluble polymers (i.e., cellulose, hemicellulose, lignin, lipids, and fats among others) are converted into biogas by a consortium of microorganisms. Biogas consists approximately of 60% methane and 40% carbon dioxide [13,14]. In the downstream processing, raw biogas is initially cleaned of moisture droplets, particulates, and hydrogen sulphide. Clean biogas can be upgraded into biomethane (>95% CH₄) by removing the CO₂ so that the purified gas can be injected into the gas grid. Upgraded biogas can also be liquefied and used as a transportation fuel. Another use of clean biogas is for cogeneration of heat and electricity in a combined heat and power (CHP) plant. The effluent needs processing so that the nutrients (N, P, K) can be reused as fertilizer in agricultural activities and

the remaining water safely discharged into natural water bodies or also efficiently reused [12].

The versatile use of biogas, covering a variety of markets like electricity, heat, and transportation fuels, is an advantage over other bio-fuels [15,16]. An integrated infrastructure such as pipelines, upgrading stations, and heat networks are required for the efficient use of biogas. Several European Union (EU) countries consider biogas as a solution for a dynamic and flexible eco-mobility culture. The use of dual-fuel engines allowed agile operation and optimization in powertrain systems [17–20].

Current practices and policies for a bioeconomy are not coherent, and more synergy and dedication towards a sustainable economy would ease the competition of green fuel technologies. Creating a bio-based economy requires significant changes in waste management and the development of practices to turn waste into reusable materials, e.g., biofuels. A new financial structure, new (ethical) norms, and education of the general public, is necessary to exchange the linear economy with a circular economy. Of utmost importance is the support of policymakers and financial investors throughout the value chain [21]. While all transitions have friction, barriers, and conflicts, a clear policy can lead to a successful environmentally-friendly system transformation.

This report reviews the essential aspects of biogas production embodied by the economic landscape, sustainability challenges, socio-ecological governance, and geopolitical situation. It deals with the *sine qua non* of the biogas industry development, and therefore, a critical review relating to the future biogas concept against the current energy industry is timely considering the ongoing debate on the use of fossil fuels in a linear economy.

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2. Manure management

The quest for devising a suitable means of waste reduction has been a matter of concern of both scientist and politicians. The production of high-value products like biogas and biofertilizer from organic waste treatment is regarded as both sustainable and environmentally-friendly [22]. Scarlat et al., by reviewing the farm manure production, estimated that approximately 1,200 million tonnes wet manure is produced per year in the EU-28 [23] (Fig. 2). Alongside this, they propped that information about feedstock utilisation and plant locations is important for a bottom-up analysis of manure potential. A projection study mapped the biogas energy potential from animal manure for the EU-28 in the year 2030, indicating the positive effect of the combined digestion of organic wastes [24]. However, a previous spatial study peered through the biogas production from crop residues and manure in the EU accounting for crucial technical, environmental, and economic constraints [25].

As with technical issues, the reactor configuration is broadly related to the properties of the feedstock. Although biogas production does not require additional equipment, amendments have to be made for the treatment of animal manure [26]. In addition, the recalcitrant trait of manure hampers the degradation of organic matter mainly due to the complex structure of lignocelluloses [27]. Li et al. (2018) assumed that cellulose yielded more methane than hemicellulose, even though that hemicellulose was degraded faster than cellulose [28]. The high content of nitrogen in animal excreta is also considered a process limiting factor and may endanger the reactor stability [29]. Ample operational experience is needed to avoid attendant risks and prevent reactor failure and biogas plant mothballing when manure is used as the substrate in AD

[30].

The biogas solution, primarily as a processing technology of biowaste cascading, gives a new opportunity to the bioeconomy where high-value products – energy-carrier biogas and bio-fertilizer - are produced [31]. The unanimity of energy crop substitution with manure is widely accepted, but this is no ground for farmers to continue their practices generating surplus manure. A vaguely worded policy for agronomy activities might concomitantly jeopardise agricultural productivity. EU's waste prevention scheme aims to dissociate the economic output and social well-being from resource preservation, energy use, and environment conservation [32]. Although current waste management policies contribute to this, the EU underlines that synergy of more concise and ambitious targets for the treatment of agricultural waste (free carbon without being efficiently utilized) could lead to a reduction of greenhouse gas emissions (GHGs) [33].

3. AD performance

The last two decades witnessed an interest in the use of microorganisms to synthesize biofuels, e.g., bioethanol, biogas or biodiesel. Monocultures (bioethanol and biodiesel) or complex microbial communities (biogas) convert organic compounds through enzymatic pathways into the energy carriers. Traditional studies to improve AD requires numerous microbial and biochemical studies but resulted in a limited understanding of the interaction of the microorganism. The introduction of metagenomics revolutionized the biofuels industry and revived the interest in the biogas economy. Metagenomics is defined as “the comprehensive study of the nucleotide sequence, structure, regulation, and function” and an in-depth characterisation and optimization

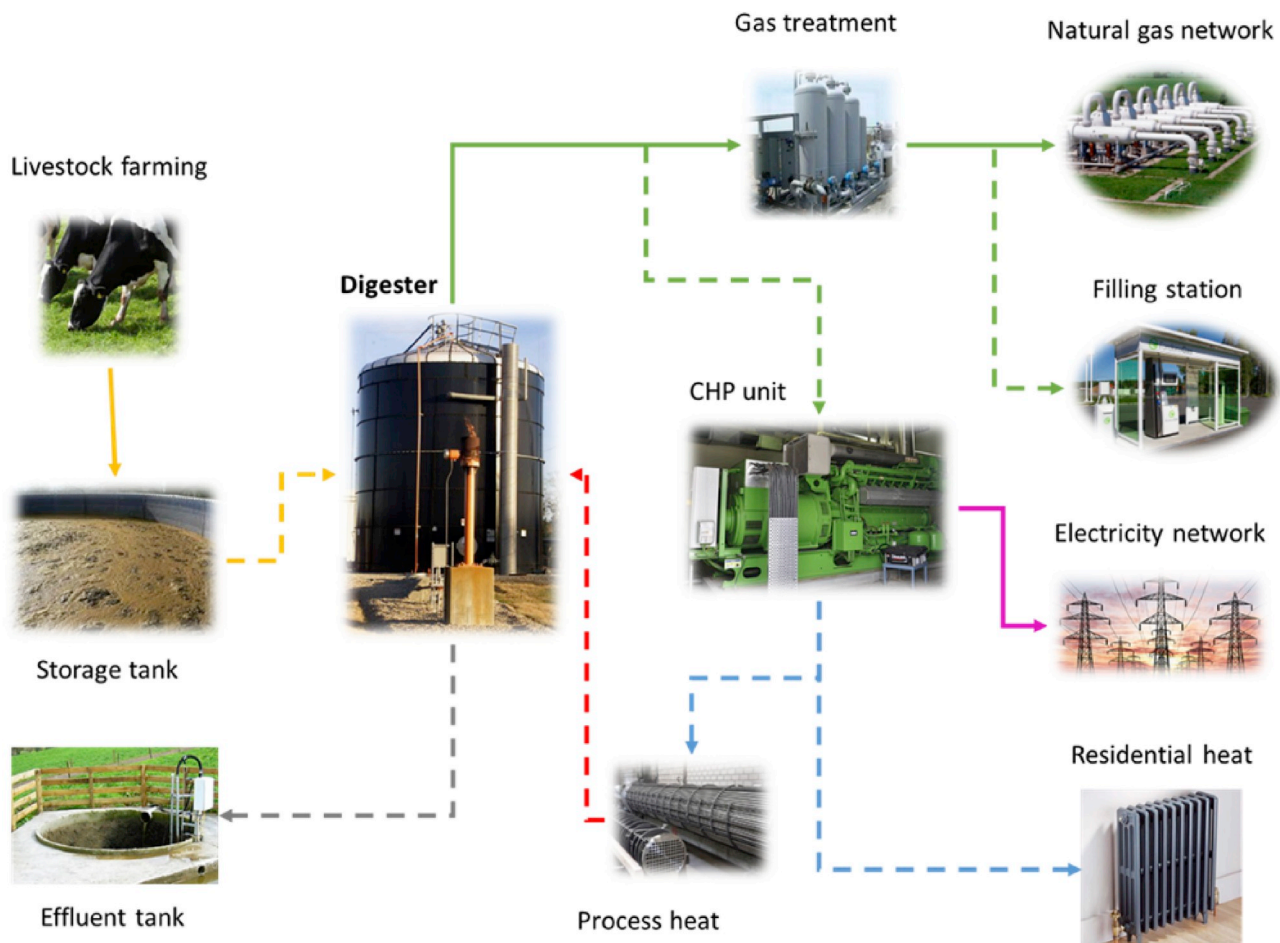


Fig. 1. Biogas infrastructure from the manure to end-products.

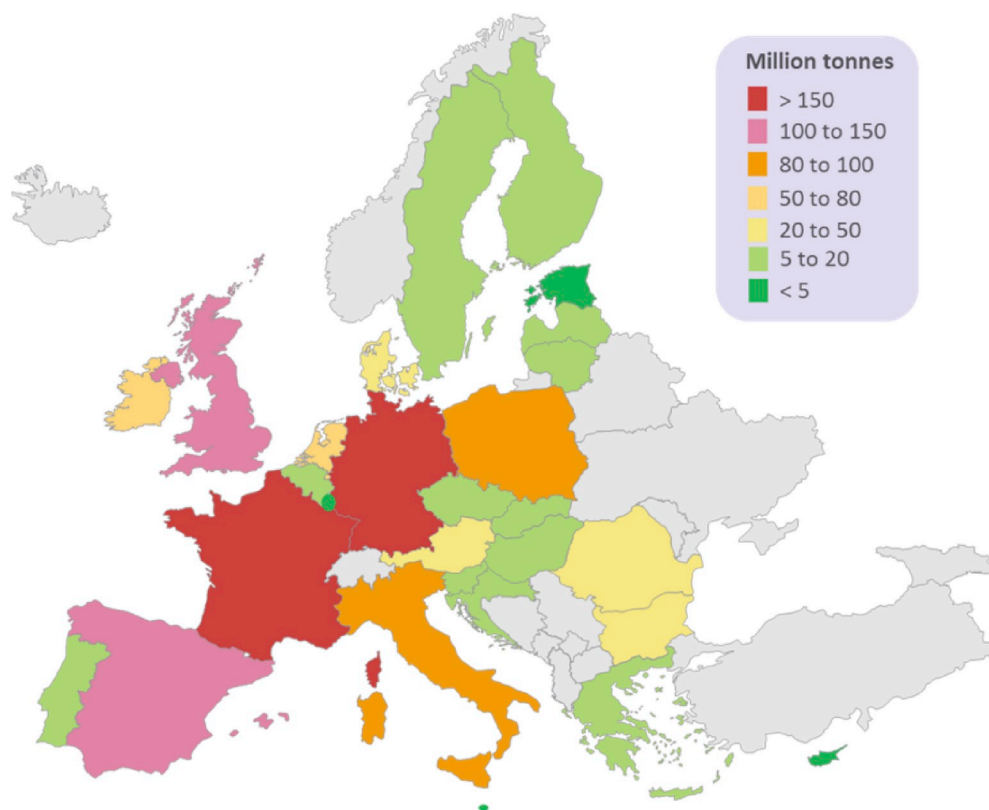


Fig. 2. Map chart of farm manure produced in EU-28 (data derived from Ref. [23]).

of microbial activities in the AD process comes within reach [34,35]. The breakthroughs in genetic engineering referred to by some as the game-changer in the biological methane economy, have led to the assurance that biogas technologists will be able to improve AD, avoid the reactor vulnerability, and increase methane yield and content in biogas [36,37]. Cardinal cause of AD plants failures worldwide is ascribed to the instability of the microbial community in the reactor. On the ground of the strong correlation between the microbial dynamics and biogas yield, the benefits emerging from metagenomics techniques have an enormous potential [38–40]. In general, researchers state that metagenomics studies will pave the way for high-yielding bioreactors in the future [41,42].

It has been extensively proven, that process perturbations, i.e., fatty acids or ammonia accumulation, deteriorate the microbial functions and eventually cause the reactor instability [43,44]. Pioneering work has identified multidimensional interspecies interactions focusing on syntrophic communities that have a significant role in the carbon cycle [45]. In addition, auxotrophy for amino acids may affect the control of carbon and energy fluxes through the reactor system and contribute to a robust microbial environment [46]. A previous study showed that amino acid auxotrophies restrain the interaction/cooperation between H_2 -producing and syntrophic alkane degrader-methanogens and can influence the operation of the anaerobic digesters [47]. Metagenomics approaches, i.e., high-throughput sequencing of community DNA and RNA, allows access to the genomic information and expression level of genes and thereby to their metabolic potential and function. This knowledge is regarded as a crucial supplement for the optimization of industrial bioprocesses treating organic waste into commodity products [48].

Microbiome monitoring allows the analysis of the complex microbial networks and the identification of functional microorganisms (Fig. 3). Metagenomics has greatly improved the knowledge pool about waste-degrading microorganisms. These techniques are applied to investigate, classify, and manipulate the genetic material from bioreactor

samples.

The operation of high-solids anaerobic digesters has procreated significant interest in exploring the activity of new organisms that can tolerate extreme conditions and capitalize on the higher lignocellulose degradation capability. The yield and rate of biogas formation from manure can be increased by a proper pre-treatment. Conventional treatment involves acid or heat, whose application is regarded as slow and expensive. These techniques can also produce intermediate products (e.g., furfural) that may inhibit AD and cease biogas production. Microbial-based treatment is considered as a grey box, and the current knowledge on the optimal combination of enzymes for accelerating biomass breakdown is limited.

Many novel enzymes that can intensify the degradation of lignocellulosic compounds exist in difficult-to-culture microbes. The omnipresence of these difficult-to-culture microbes in animal guts obstructs the understanding of their genomic traits. The adoption of metagenomics tools for the microbial analysis of termite hindgut resulted in the decryption of an astonishing number of active lignocellulose-degrading enzymes [49,50]. Auer et al. (2017) tested the impact of termite gut microbiome in the anaerobic digestion of lignocellulosic waste [51]. They conducted mesophilic anaerobic treatment of wheat straw with four higher termite-based inocula and up to 45% (w/w) of wheat straw degradation was observed. Mikaelyan et al. (2014) found cellulolytic bacterial communities in the hindgut of *Nasutitermes* spp. a higher termite, and pointed out its wood-fibers degrading potency [52]. From an economic perspective, a full-scale application of hindgut-based microbial communities and enzymes is not viable because of the complexity of the procedure.

The understanding of the biochemical machinery used by the termite bacteria to hydrolyze the long-chain polysaccharides, specifically cellulose and hemicellulose, may offer new technological avenues for the optimization of manure-treating bioreactors. Molecular techniques have been employed to understand the microbial dynamics of the anaerobic digesters in laboratory situations. Now it is up to the biogas industry to

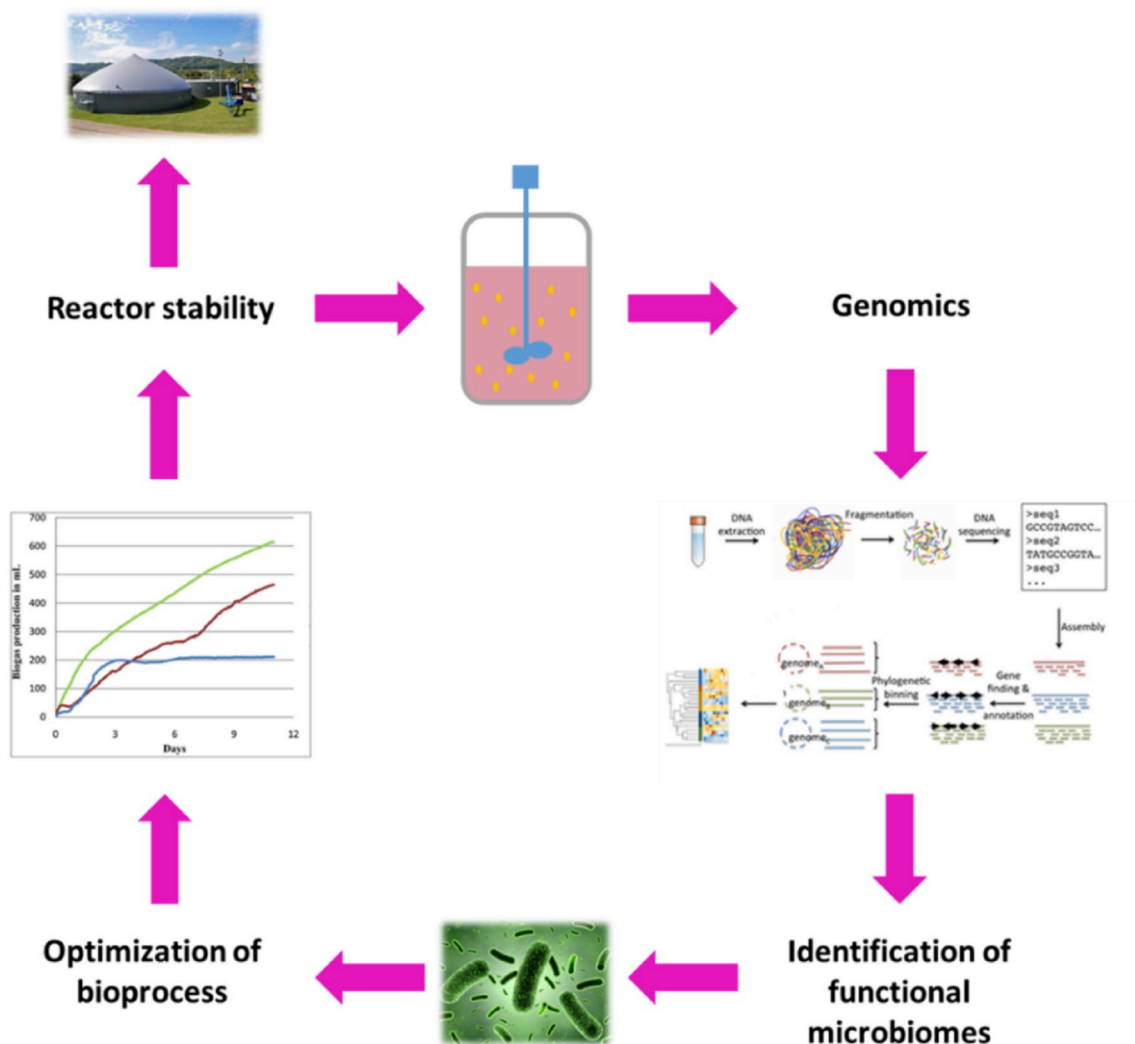


Fig. 3. Strategy for full-scale bioreactor improvement by incorporating metagenomics (adjusted from Ref. [42]).

make use of the possibilities that the biomolecular techniques offer [53]. The effects of microbes-functionality plexus on the anaerobic digester performance has been reported in a previous study [54]. A considerable number of next-generation biofuels-associated processes and targets describe the *status quo*; however, considering the long ratification times, too little of them can be explored for commercial applications. The biotech industry, research innovation hubs, and academic research institutions can *en bloc* engineer microorganisms and/or biocatalysts with better characteristics and low production cost resulting in innovative, higher-yielding, anaerobic digesters [35,55].

4. Economic landscape

The spectrum of biogas applications in the field of global mobility and power provision creates a broad basis of potential customers. The *ad hoc* strategy launched in 2012 by the EU fructified the total European bioeconomy augmenting the turnover from 2008 to 2015 by 9.6% [56]. Business leaders envision biowaste as a viable energy source to produce biomethane that can have benefits that go beyond climate change and create a healthy economic arena. It is documented that aligned economic and environmental considerations may implement well-driven animal slurries markets [57]. Reinforcing efforts to adopt waste management practices is possible; however, eco-friendly and profitable approaches to reduce wastes is indispensable to re-direct the linear economy into a sustainable trajectory.

Mitigation of GHGs, secure supply of energy and commodities, and activities to improve economies in rural areas are drivers for the transition [58]. The leapfrogging to biogas and its integration as energy carrier biofuel can have a positive contribution to the overall cost savings and will create a roadmap to establish attractive economic activities. Despite that government subsidies can be a stimulus to the biogas industry, investments in new biogas plants slowed down over the last years in the European region [59]. The total EU employment and turnover in the biogas sector decreased from 83,700 jobs in 2015 to 76,300 in 2016 (−9%) and from € 8.7 to 7.6 billion (−12%), respectively [60]. It is also implicit that a green value of the end-products can affect the business project viability. In general, economic drivers are those who can underwrite the financial and technical assurance of a biogas plant.

It is noteworthy that the number of biogas plants pursued its upward trend (increased 68.7% in 2010); however, it has been losing pace since 2011 (increasing 18.0%, 11.4%, 6.1%, 14.8%, 3.6%, and 1.3% respectively) as shown in Fig. 4. A probable reason for this decline is the implementation of regulations that discourage biogas production and is presumably compounded by less attractive electricity payment terms.

Although a nexus between the lab studies and commercialization emerges, replacing incumbent businesses and building biogas plants are an insecure undertaking for investors. The uncertainty of the economic return on the investment, the peddling of business plans, and the promotion of hedge funds hinder the growth of the renewable biofuel industry [61]. One of the criticisms levied at the biogas market has been

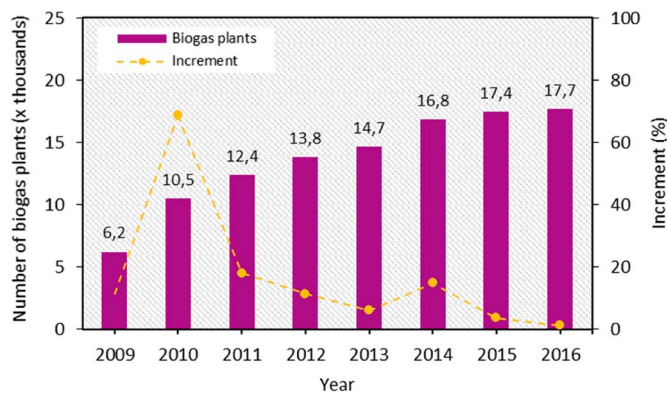


Fig. 4. Number of the biogas plants operating in the EU-28 (data derived from Ref. [58]).

the lack of a standardized trade framework and consistent agreements. The European feed-in tariff policy is nevertheless a pivotal incentive for the producers to sell biogas-based energy at a fixed rate for a specified period and delete the uncertainty derived from renewable energy projects [62]. Regulations relating to the feed-in tariff include three key clauses based on the costs of biogas generation: guaranteed access to the grid, invariant purchase contracts, and relatively long-term payback periods (15–20 years) [63].

Biogas has different applications while mainly being used as fuel in the residential or industrial sector to obtain heat or/and electricity. However, the optimal and cheap use of biogas is still not apparent [64]. During the period 2012–2016, electricity and heat production increased by 35.1% and 97.6%, respectively (Fig. 5). The most common equipment used for heat and power are boilers, internal combustion engines, Stirling engines, and gas turbines. These systems do not require high-quality gas as input, so expensive biogas upgrading is not needed. For instance, Stirling engines can use gas with a CH₄ molar concentration of 35% [65].

Several studies refer to the environmentally and economically efficient application of these systems fed with biogas compared to those using fossil fuels [66–68]. Goulding and Power compare the techno/economic performance of biogas CHP and transport biomethane at small/medium scale in Ireland. They concluded that the biomethane pathway is more optimal. However, the final impact depends on parameters like policy, technology maturity, and biomethane demand and price [69]. Zappa et al. (2019) examined several scenarios for the future energy system of Europe in 2050. Their model was based on 100% renewable energy sources embodying different levelness for future

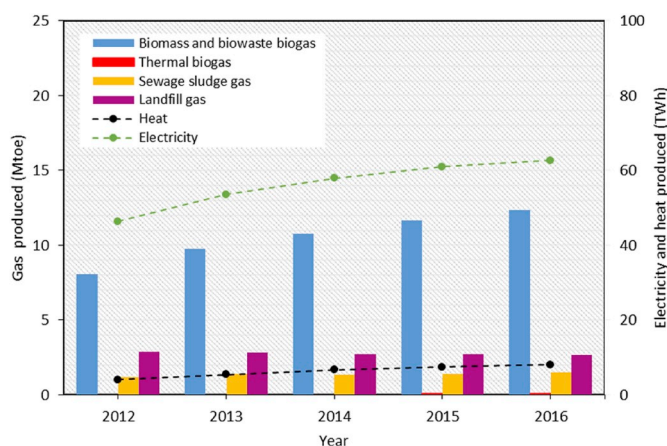


Fig. 5. Gross electricity (in GWh) and gross derived heat (in ktoe) production from biogas in the EU-28 from 2012 to 2016 (Data derived from Ref. [60]).

energy demand and technology availability. They concluded that Europe must increase the biogas capacity deployment to at least 6 GW/year [70]. Another techno-economic study unveiled that the biogas CHP system is more beneficial than the fossil-fuel based energy system with an annual cost-saving and profitability index of €65,017.78 and 60.99%, respectively [71]. The authors also reported that by replacing the conventional system with a biogas-based system resulted in a 529.65 tons per year CO₂ emission reduction. Akulut examined the techno-economic feasibility of a farm-scale biogas plant with a CHP unit using cow manure as feedstock and reported a reduction of 7506 tons CO₂ per year [72]. The authors indicated that a plant with dairy cows renders a good economic project investment showing a positive NPV of 27.74 million €. In addition, Kluczek (2018) reported an intrinsic reduction of heat and GHG emissions by modifying the integrated bio-digester CHP unit. The pre-heating of manure can result in up to 20% energy savings in comparison to the conventional system [73]. Another study by Koc et al. showed beneficial performance results of the biogas fuelled combined heat and power (CHP) engine through the use of regeneration. They performed exergy analysis for the organic rankine cycle using gaseous exhaust waste in combination with heat recovery [74].

CCHP (combined cold, heat and power) or trigeneration technology is also considered a sustainable concept for efficient energy production. Stanek et al. compared the exergo and thermo-ecological cost of a photovoltaic plant with a CHP engine fed with biogas. They reported that the thermo-ecological cost value depends on the type of generated carrier (electricity/heat/cold) [75]. Gazda and Stanek (2016) examined energy and ecological efficiency of the integrated biogas trigeneration and photovoltaic plant. Their results depicted savings in the primary energy consumption as well as GHG emissions reduction of 50% and 65% respectively [76]. Lamidi et al. (2017) indicated that the efficiency of biogas trigeneration systems depends on the season. The primarily conducted LCA showed energy losses during the wintertime due to the temperature of manure that enters the digesters [77].

On the other hand, upgraded biogas (biomethane) can be also be employed for electricity generation in fuel cells, a concept that is still under research. Gandiglio et al. investigated the life cycle of a biogas-fed solid oxide fuel cell integrated into a medium-sized wastewater treatment plant and concluded that it is not yet a beneficial concept. They reported that it is critical for a wastewater treatment plant to have a unit like a CHP that can deliver sufficient thermal and electrical energy [78].

The biogas produced from biomass and biowaste increased 52.96%, indicating that biomass and biowaste are the main contributors to the biogas commercialism. Sewage sludge gas showed a rise of 27.9% while the landfill gas showed a decrease of 7.4% (Fig. 5).

The implicit price ceilings of gas relapse the market, thus the venture capital firms are more interested in alternative energy sources like solar or wind. Private sector actors underscore that the consensus of the biogas credibility and viability is affiliated to the net energy gain, technical complexity, and socio-environmental impact. A previous study examined the economic implications of the biogas installations in the agro-industrial sector and revealed that incremental revenues could be achieved [79]. Biogas can have a dual role in the bioeconomy; as an end-product for consumers replacing fossil-fuels derived products, and as a technique to treat low-value biowaste sustaining the green transition [80]. However, the slow development of new technologies and scientific breakthroughs in gaseous fuels production might erode its competitiveness [81].

5. Socio-ecological governance

The misapprehension that green fuels contribute to the net GHG emissions magnifies the negative opinions leading to congestion in the bioenergy landscape. The environmental impact of biogas production is significant to climate change, and particularly over the land-use, water scarcity, food security, and emissions footprint. A moratorium on the

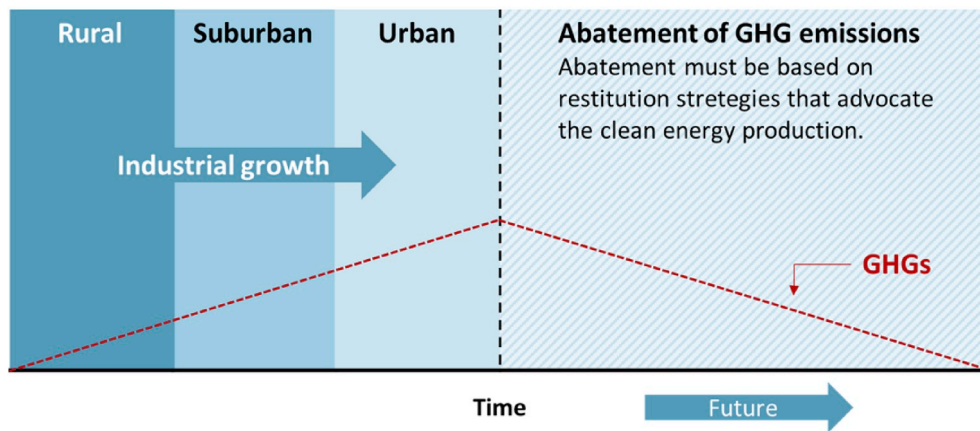


Fig. 6. Interrelationship of urbanism, industrialization and GHGs.

expansion of biogas is essential to foster conservation and development concurrently. The environmental deadlock requires a cross-cutting concern for drastic alterations; hence, the technological ensemble is pivotal for competent combined waste management and power generation. Alongside the uncertainty on emission savings, there has also been consternation over the use of food crops. The use of energy crops instead of food crops counteracts possible food security issues.

For several years, a debate is going on over the balance between the natural resources extraction (e.g., land and water) and the environmental conservation efforts. Biowaste upcycling contributes to a decrease in the extraction of these natural resources and brings further disturbances to the environment to a halt. The closed-loop approach in animal manure treatment generates electricity (via biogas and CHP), water and fertilizers for agriculture, a reduction in solid waste, and a decrease in externally purchased energy [82].

The adoption of symbiotic flows, in terms of waste and energy, and processes, can accelerate the GHGs mitigation and reinforce ecological sustainability [83]. Previous technical studies emphasize the territorial and environmental-friendly features of AD for bioenergy production, i. e., decrease direct and collateral GHG emissions and waste reduction [84]. Because of the global awareness for an ecological disaster and the necessity for sustainability, notable efforts and interventions are pursued to ensure that the green development with the accompanying widespread benefits for economies takes place [85]. Urban clustering in conjunction with its increasing industrialization, has led to serious pressures on the global ecology [86].

Urbanism is an additional factor in the sustainability policies and its industrialization has to be reckoned with (Fig. 6). The demand for energy and waste generation are high in urban areas and result in a large environmental pollution load in cities that affect the health and quality of life of the urban population. Thus, global awareness for the reduction of GHG emissions is intrinsic for the implementation of clean energy strategies and policies.

The above caveats demand that it is essential to assess both the demographic and ecological transition and economic growth in parallel. Their interdependence is a critical theme that raised speculation whether or not that relation is complex [87,88]. Several scientific reports raise the question if population growth and income influence the ecology [89–92]. Galeotti et al. (2011) empirically studied the impact of uncontrolled population growth on the environment [92]. Their study conducted an insightful econometric analysis of demographic and ecological transitions.

Harte (2007) reported that population size is a dynamic factor in the degradation of environmental goods (e.g., water, air, soil, and biodiversity). He zoomed in on the cloudy relationship between population growth and the sustainability of the human enterprise [93]. Martínez-Zarzoso et al. (2007) modelled the impact of population CO₂

emissions for the case of Europe [94]. They concluded that population growth of the current EU members is more impactful on the CO₂ emissions than the older ones. The EU member states have to ascertain this ecological aspect and take population growth into account in future agreements on mitigating climate change.

Bridging ecological requirements with sociotechnical factors assertively support the energy transition framing and revives competitiveness. A previous study proffered an approach that draws on the strengths of combining technical standpoints and societal hallmarks [95]. Socio-cognition models have been formulated for assessing the development of the biogas sector in northern Europe [96]. Scrutinizing the socio-cognitive evolution facilitates the understanding of ups and downs in the biogas development trajectories and hastens the mutual interaction and learning of stakeholders in the biogas industries [97].

6. Sustainability challenges

Despite the interest in improving the biofuel production technologies, the execution of bio- and circular economy does not easily take off. The fact that bioeconomy is considered sustainable is controversial amidst the scientific community, as a bioeconomic transition can also have negative impacts on sustainability [98]. So far, the attempts of the oil and gas enterprises to incite sustainable actions had no profound effects. Sustainable engineering serves as an intermediary to concretize the applicability of biofuel production technologies embedding techno-economic, socio-environmental, and geographical realities [99]. Franska et al. (2014) [100] explored the translation of socio-environmental risks in large-scale projects. They revealed that large businesses mining for natural resources generate societal and economic conflicts. European Vanguard, prioritizing low-GHG biofuels, imposed higher market standards to spur up the biogas industry to a higher sustainable level. It becomes clear that all stakeholders, from the European to the local level, including governments, businesses, researchers, and citizens have to take united actions to change from a linear, oil-based economy into a sustainable circular economy based upon sustainable resources.

The sustainability concept manifests an evolving scheme that is characterized by an apparent environmental policy landscape, demographic attitude inversion, upfront technological requisite, changing economic reality, and inaugural global engagement (Fig. 7). From the bioeconomy aspect, the sustainability concept implies interactions to redeem quality and value.

Central to adopting the necessary systemic alterations and advancing the transition will be to find strong sustainability incentives. Economic incentives force firms to find the most appropriate route to incorporate anti-pollution measures. To date, life cycle assessments (LCA) are employed to indicate and evaluate factors and sustainability metrics of

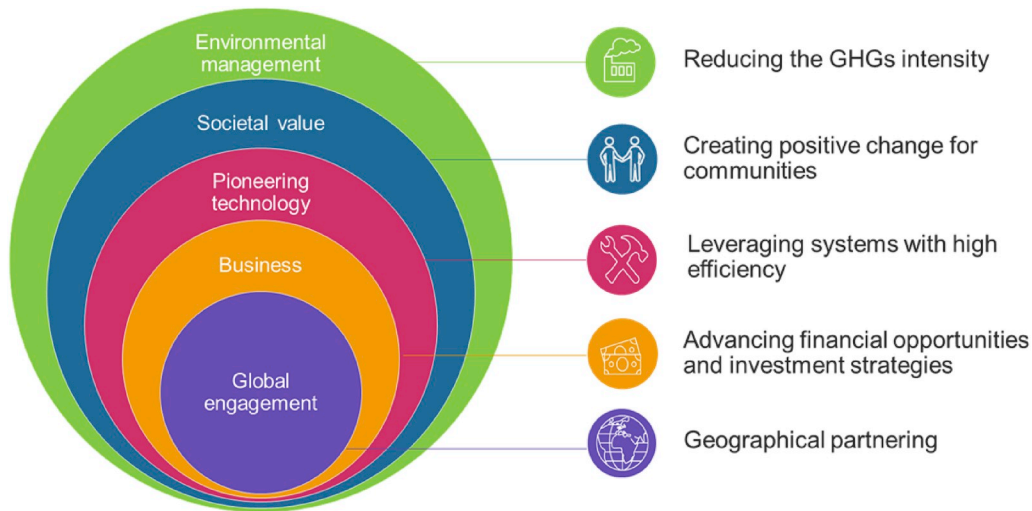


Fig. 7. Factors engaged for sustainability.

concern in biogas systems [101]. LCA articulates a range of input-/outputs and boundaries for their assessment, and notably establishes a balanced system of reference. In the particular case of biogas, the environmental, energy, and economic performance of biogas systems have been previously studied using a life-cycle perspective [102–104]. Despite that anaerobic treatment of organic waste or manure can contribute to the reduction of GHG emissions, a negative cohesion in the agricultural sector and waste-based biogas value chains may occur [105]. Preceding reports have compared the ecological milestones and economic pledges to attain a reconciliation of the emissions targets [106,107]. Knowledge acquisition and assistance to decision-makers necessitate the use of environmental decision support tools. Santos-Clotas et al. (2019) developed an environmental

decision-making system which is updatable with new technical and scientific literature data [108].

Lyng and Brekke (2019) investigated the environmental impacts of biogas as a transport fuel compared to natural gas, biodiesel, and fossil diesel. The concluded that biogas has a relatively low impact on the environmental impact categories accessed [109]. Florio et al. (2019) also compared the environmental impact of cogeneration of electricity and heat using biogas or fossil fuels [110]. The results showed that the substitution of fossil fuel with biogas has a positive impact on emission footprint and fossil fuel consumption with approximate savings of about 0.5 kg oil eq/m³ of biogas [110].

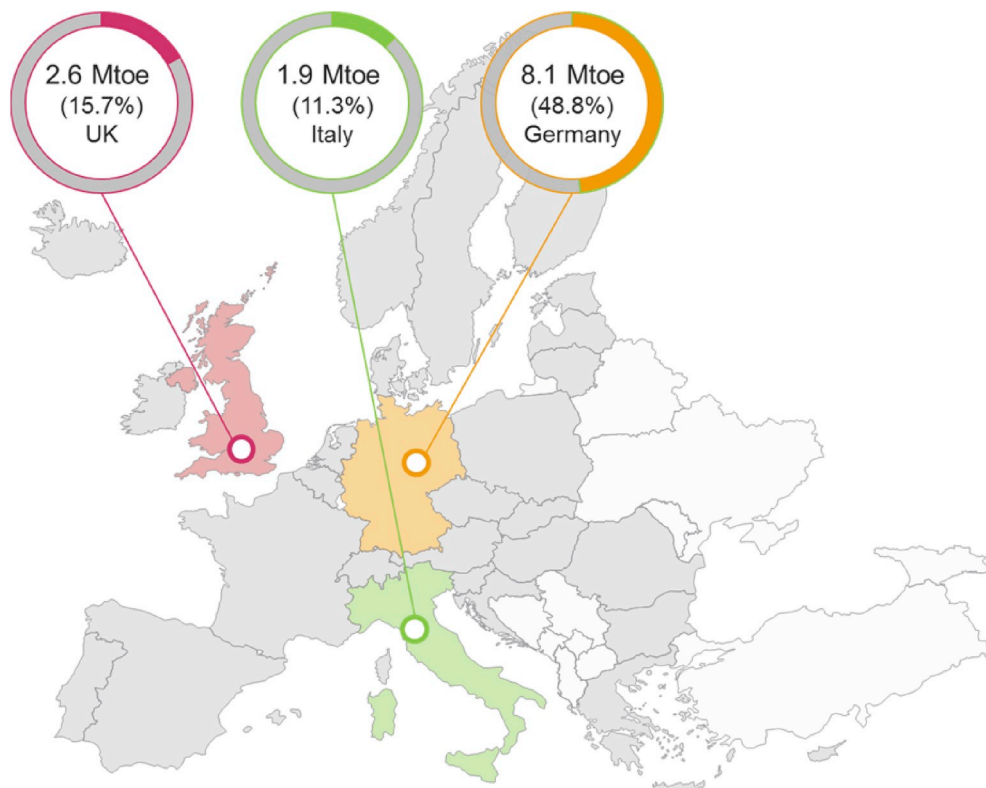


Fig. 8. Primary energy production (in Mtoe) from the three main producers in the European Union in 2016 (Data derived from Ref. [60]).

7. Geo-political environment

Political uncertainty stalls the biogas industry as the existent policy seems to be daunting or hotly contested. The barrage of legal restructurings does little else besides reducing the entrepreneurial activities and relapsing the green development. Pausing of the gas industries with the European mandates concerning the addition of renewable fuels into the grid as well as arbitrary blending are still lingering, and the breaks can have harmful repercussions on the global green economy [111]. International organizations acknowledge that better stewardship may overcome law defiance and decrease excessive emissions. In 2015, the EU amended the Directive (EU) 2015/1513, which considers the application of methane produced from biomass and biowaste in AD [112]. However, attempts to treat animal slurries in rural areas are futile because the policy does not allow this kind of feedstocks. The vision spawns an oblique scheme and entails perversity of the energy-economic system, and subsequently, the appeal of biogas ensues [113].

The compliance with the new directives is intended to drive massive economic and spillover effects in the future by softening the impact of the reformed regulatory framework and encouraging the pursuit of green technologies. The bioenergy sector has been subject to upheaval due to geopolitical conflicts. The independence of the EU on foreign gas resources and the financial escalation of agricultural farms around Europe are profound causations of shifting to bioeconomy. However, European think-tanks go beyond simply energy independency and adopt a more proactive attitude on certain core principles which concatenate and underpin bioeconomy and sustainability. All EU Member States have a biogas energy sector; however, Germany, UK, and Italy provide three quarters (75.8%) of all European output (approximately 16.6 Mtoe) (Fig. 8).

The Renewable Energy Directive (RED) obliges that 20% of the total EU's energy consumption must come from renewable energy source by the end of 2020 [114]. The enactment of reforms can clear up the policy landscape and must not be confined to the geography, but taking into account the European Union goals. Some significant alterations have been made to the schedule, and many companies have importuned for off-take agreements as part of a strategy to establish stable and reliable markets for biofuel suppliers. Assemblage, comprehension, and codification of technological experiences in local practices expedite the realization and retention of the biogas technology at the global level [115].

8. Evaluation

Research efforts provide insights into the technological barriers for a transition to bioeconomy. AD is regarded as an ecological approach for energy recovery in rural areas and for the production of valuable end-products from organic waste that can improve the agricultural economy [116,117]. However, there are ambiguous facets not clearly investigated at the experimental level, i.e. the influence of the composition and pre-treatment of waste streams, the composition, and activity of the microbiome, and the design of the AD reactors on the quality and delivery of constant amounts of the end-products. The treatment of the vast amount of animal manure in farm-scale digesters will play a vital role in the agricultural and energy value chain. Emerging technologies like metagenomics will pave the way for efficient biogas production from animal slurry since a broad consortium of microorganisms largely determines the performance of an AD process. Considering the above facets of the biogas industry, anaerobic treatment of animal slurry represents a promising solution to alleviate inhibitors of the agricultural economy, and attain sustainability at the provincial level.

9. Conclusions

This review updates the AD establishment around the world and its impact on the environment and the transition from a linear economy to a circular, sustainable green economy. Despite the biogas advantages in

terms of providing electricity, heat, and gas for the grid, advocates and stakeholders face unmet challenges. The above-mentioned aspects show that biogas technology remains in the lower level of renewable energy deployment throughout the EU because the policy landscape remains fuzzy and difficult to deal with. Developing a sustainable market for methane/biogas and raising public awareness remain critical challenges. The biogas industry has struggled in the past in terms of credibility but driven by more scientific/technological breakthroughs, it grew substantially, supported by governmental assurances. Research initiatives are recommended by the European Union to enhance the biogas sovereignty and to add benefits for the society and industry. Bringing together governmental bodies, companies, research institutes, and financial institutions will drive the biogas sector in line with main strategic objectives and confirm that biogas production can be managed with as much rigor as other challenging, sustainable processes. Given its huge potential for eco-financial benefits, biomethane has tremendous commercial opportunities.

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